Computer Modeling Laboratory 7

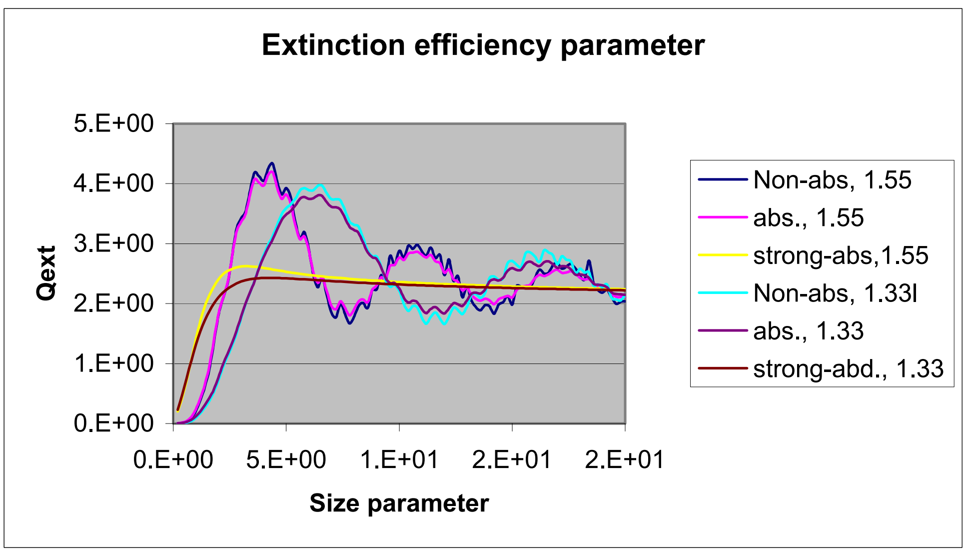
Written report due: Nov. 3

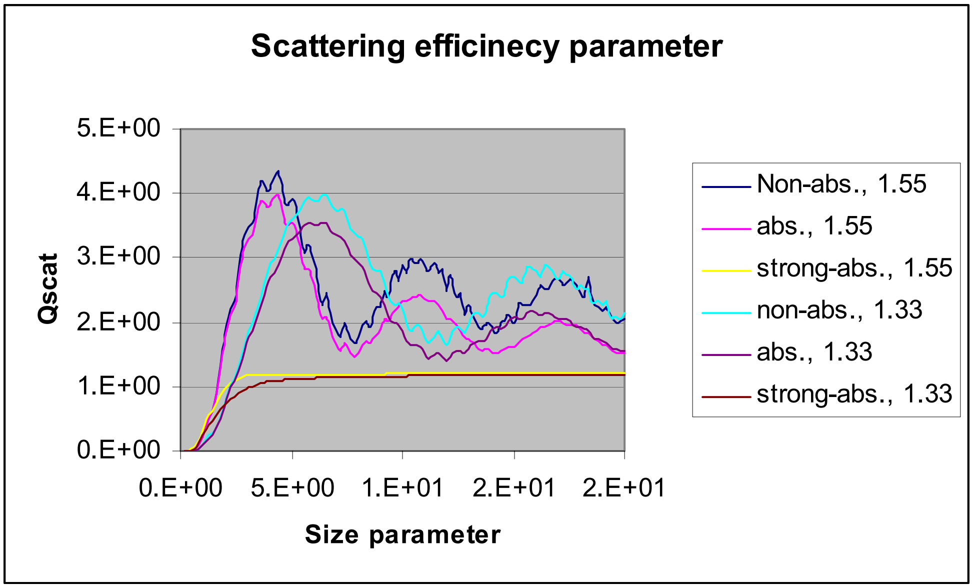
Modeling the optical properties of spherical particles using Mie theory

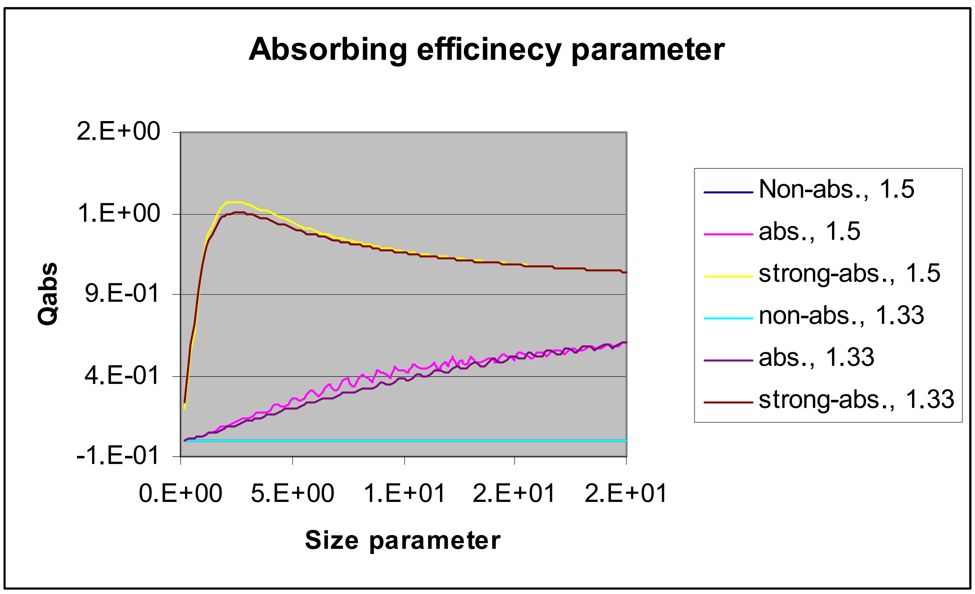
Instruction: to calculate the optical characteristics of a single spherical particle click on [RUN MIE]

TASK 1

Compute and plot (as a function of the size parameter) the extinction Qe, scattering Qs, and absorption Qa efficiencies. Consider the size parameter from 0.2 to 20 and three cases of refractive indices: m = 1.5 (non-absorbing aerosol); m =1.5-i0.01 (absorbing aerosol); m=1.5-i0.5 (strong absorbing aerosol).







a) How does an increase of the imaginary part of the refractive index affect the efficiencies?

When there is no absorption, scattering efficiency plot shows a series of ripples, where major maxima and minima are due to interference of diffracted and reflected light. As size parameter increases, it approaches geometric limit, where asymptotic value of extinction efficiency approaches 2. In the case of the geometric limit, a particle removes twice as much of incident light that it can intercept (Liou, 2002, p.190). The total amount of energy that is removed is twice the size of the geometric area of the particle.
Increase in absorption (imaginary part of refractive index) smoothes out scattering and extinction efficiencies (less ripples), and also reduces maximum in scattering efficiency due to loss to the absorption. In case of strong absorption the effect due to diffraction and transmission is reduced, thus there is no interference (no ripples). Increase in imaginary

part affects the maximum in extinction efficiency that shifts to a smaller size parameter and is also reduced in amplitude. The asymptotic value of scattering efficiency reduces from 2 (no absorption) to 1.2 (strong absorption). In addition an increase in imaginary part increases the absorption efficiency.

b) For each case (i.e, non-absorbing, absorbing and strong absorbing), show how the variation in the real part of the refractive index affect the efficiencies.

A decrease in real part had reduced maximum of the extinction, scattering and absorption efficiencies. It also shifts maximum to a larger size parameter. This is because efficiency is proportional to a refractive index (through a and b coefficients, Liou, eq.(5.2.74)).

c) Consider a layer of 1 km thick consisting of absorbing and non-absorbing aerosol particles. What aerosol characteristics (in addition to Qe, Qs and Qa) do you need to know in order to calculate the total aerosol optical depth and single scattering albedo at this layer?

The optical depth is the product of extinction (scattering, absorption) coefficient and amount of the particulate in the atmospheric layer. The extinction, scattering, and absorption coefficients are defines as:

$$\beta_e = \int_{r_{min}}^{r_{max}} \sigma_e(r) N(r) dr$$

$$\beta_s = \int_{r_{min}}^{r_{max}} \sigma_s(r) N(r) dr$$

$$\beta_a = \int_{r_{min}}^{r_{max}} \sigma_a(r) N(r) dr \qquad [14.24]$$

Efficiencies (or efficiency factors) for extinction, scattering and absorption are defined as

$$Q_e = \frac{\sigma_e}{\pi a^2} \qquad Q_s = \frac{\sigma_s}{\pi a^2} \qquad Q_a = \frac{\sigma_a}{\pi a^2} \qquad [14.16]$$

Thus, to find extinction cross section we need to know radius of particle, *a*; and to find extinction coefficient, we need to know particle size distribution, *N (r).*

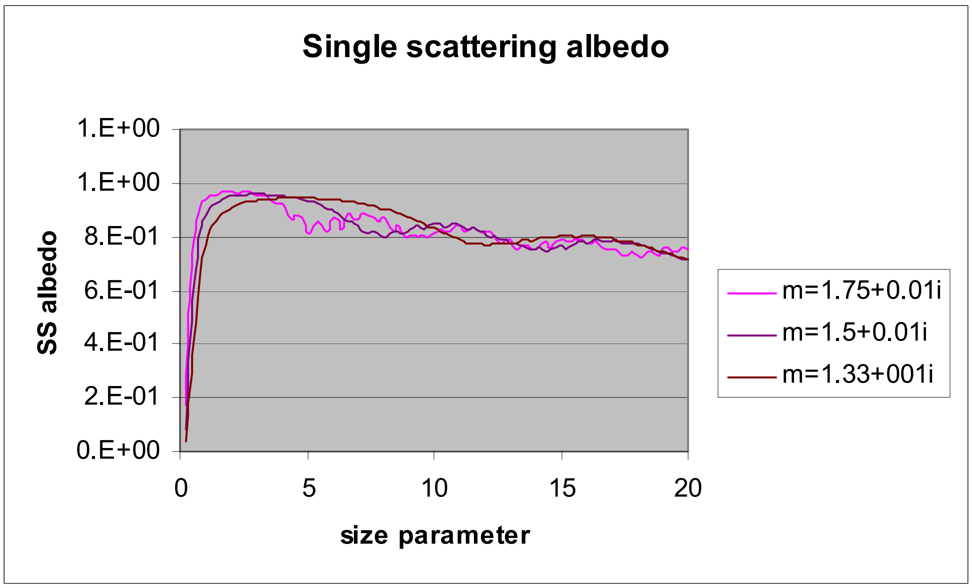
To find a single scattering albedo, we need to find absorption and scattering coefficients (as described above), that also depend on particle size distribution:

$$\omega = \frac{\beta_s}{\beta_s + \beta_a}$$

TASK 2

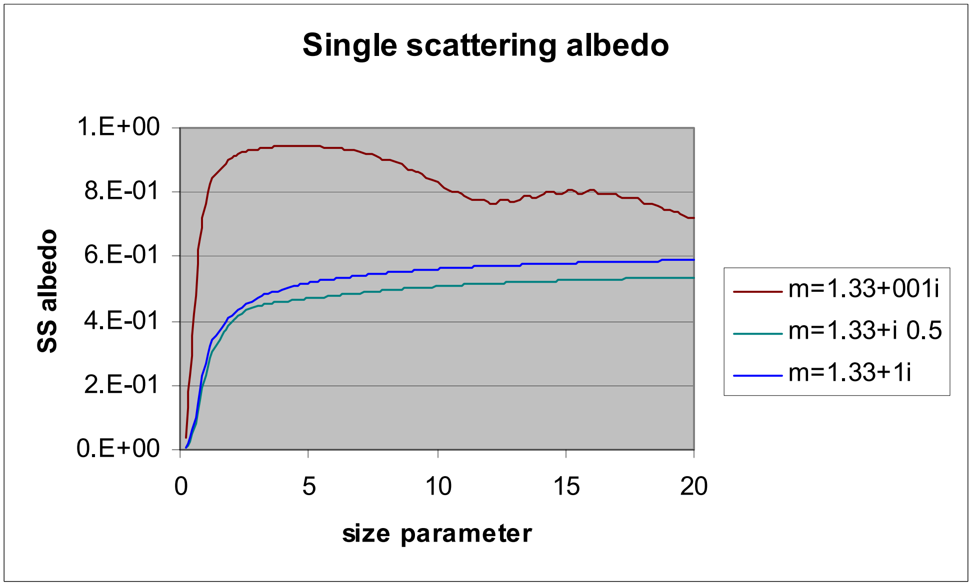
The single scattering albedo of aerosol particles depends on the refractive index, but the relationship is not simple and a function of the particle size. Although an increase of the imaginary part of the refractive index often corresponds to a decrease in the single scattering albedo, it is not always the case. Investigate the relashionship between the single scattering albedo and the imaginary part of the refractive index for the representative characteristics of atmospheric aerosols (real part of the refractive index is from 1.3 to about 1.75; imaginary part is from 0 to 1; size parameter is from about 0.2 to 20).

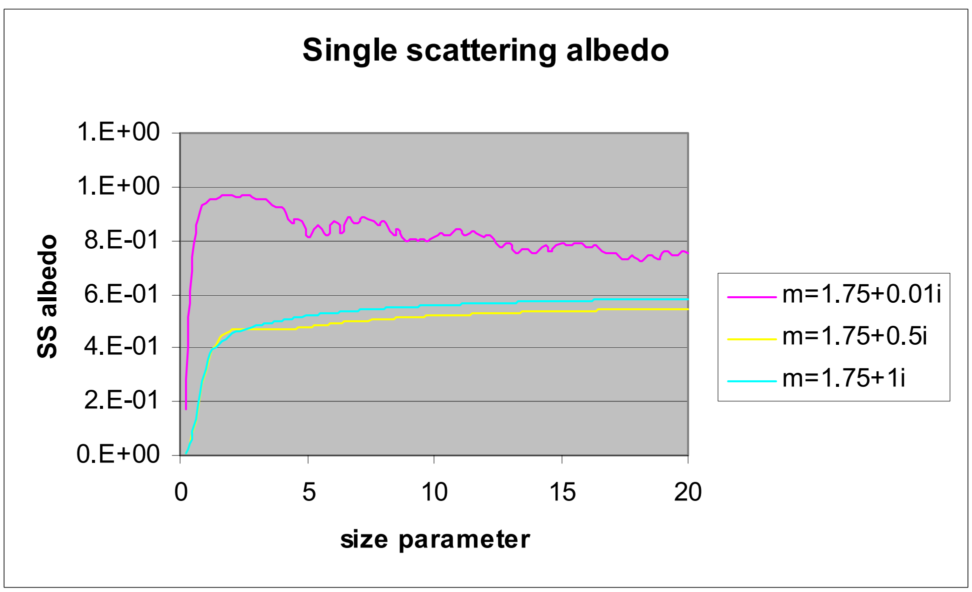
When m_i=0, particle is a perfect reflector; thus, SSA is 1 and does not depend on size parameter.



The single scattering albedo is related to the ratio between scattering and extinction efficiencies, and thus its behavior is defined by dependence of scattering and extinction efficiencies on size parameter and on refraction index. In general, when size parameter is small (less than 5: for example, particles with small radius, when wavelength is fixed) SSA increases sharply with size parameter. For larger size parameters it starts to level off and approaches an asymptotic value of about 0.6, which corresponds to asymptotic values of scattering and absorption efficiencies. The increase in real part of the refractive index creates series of maxima and minima and ripples, which is similar to the effect of the refractive index on the scattering efficiency. There is also a shift of the SSA maximum to the smaller size parameter with the increase in real part of the refractive index

In most of the cases, an increase in absorption means larger extinction (sum of scattering and absorption coefficients), and thus, smaller single scattering albedo (SSA). Increase in real part means larger scattering in maximum of interference.

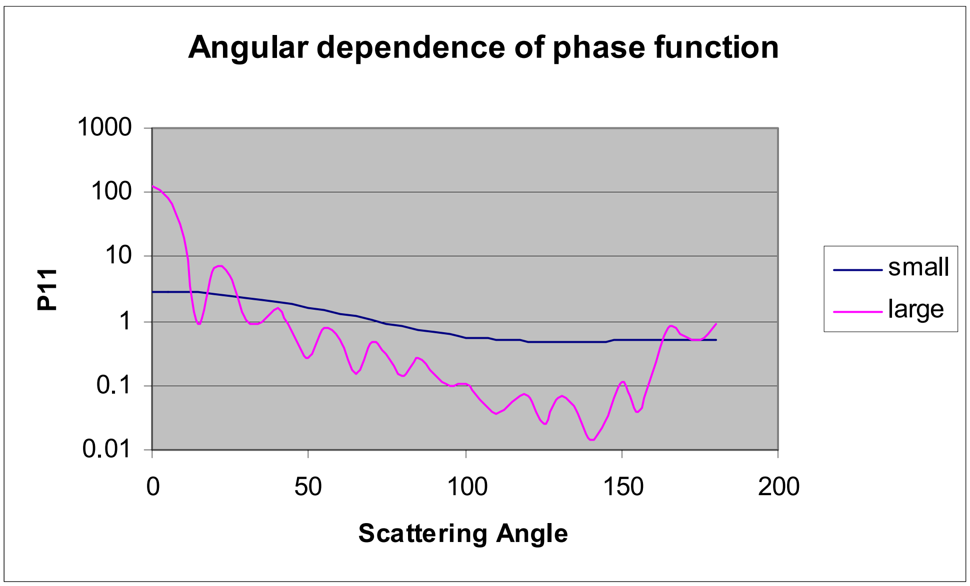




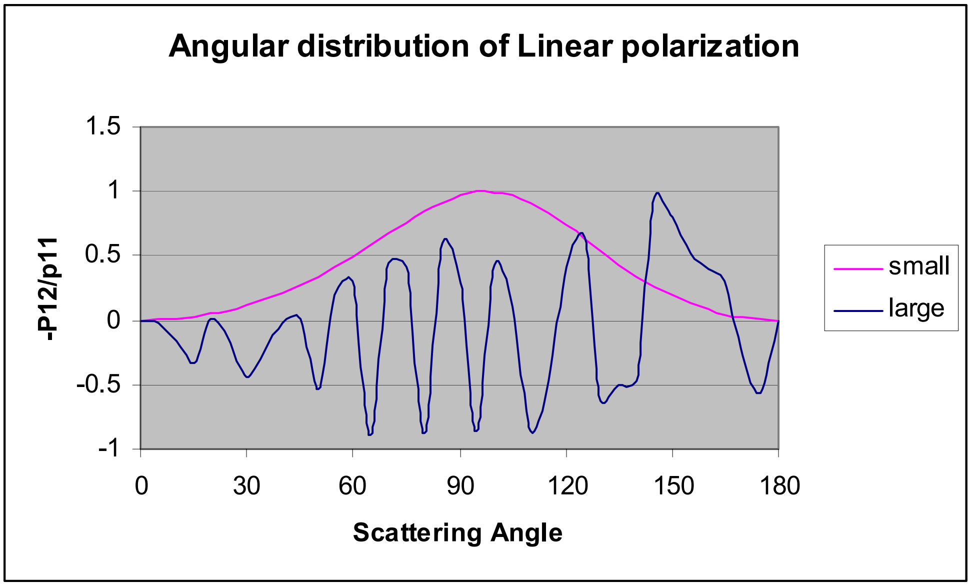
For the same real part (m=1.75 or m=1.33), increase in imaginary part of refractive index (between 0 and 0.5) results in decrease of SSA. For the same imaginary part (0.01), reduction in real part (1.75, 1.5, 1.33) reduces SSA. However, there is small increase in SSA when the real part of refractive index is large and imaginary part increases from 0.5 to 1. For large size parameter, the reverse of the relation between SSA and imaginary part of refraction index happens also at smaller m_i. Thus, in the case of large aerosol particles an increase in absorption reverses the typical relation between SSA and imaginary part of refractive index. For increased absorption the scattering efficiency becomes constant at large size parameter sooner than absorption efficiency that continues to decrease. Thus, SSA for large size particles will increase with increased absorption.

TASK 3

For the remote sensing applications it is important to know the angular distribution of scattered radiation. Compare the angular dependence of the phase function (i.e., the element P11 of the scattering phase matrix) and the degree of linear polarization (i.e., LP = - P12/P11) of radiation scattered by smaller (r = 100 nm) and larger (r = 1000 nm) aerosol particles at a wavelength of 500 nm. Consider absorbing aerosols with m=1.5+i0.001 .



When the wavelength of the incident light is smaller than radius of a particle, the light will go through multiple reflections within particle. Phase function for larger particles (x=12.6) shows very strong forward scattering, secondary peaks and ripples (multiple reflections), as well as increased scattering at 180 degrees. At the same time, small particle (x=1.3) has radius that is smaller than wavelength of the electromagnetic wave. It results in strong diffraction of the incident wave, whereas there is no reflection. It creates smooth phase function that decreases with scattering angle.

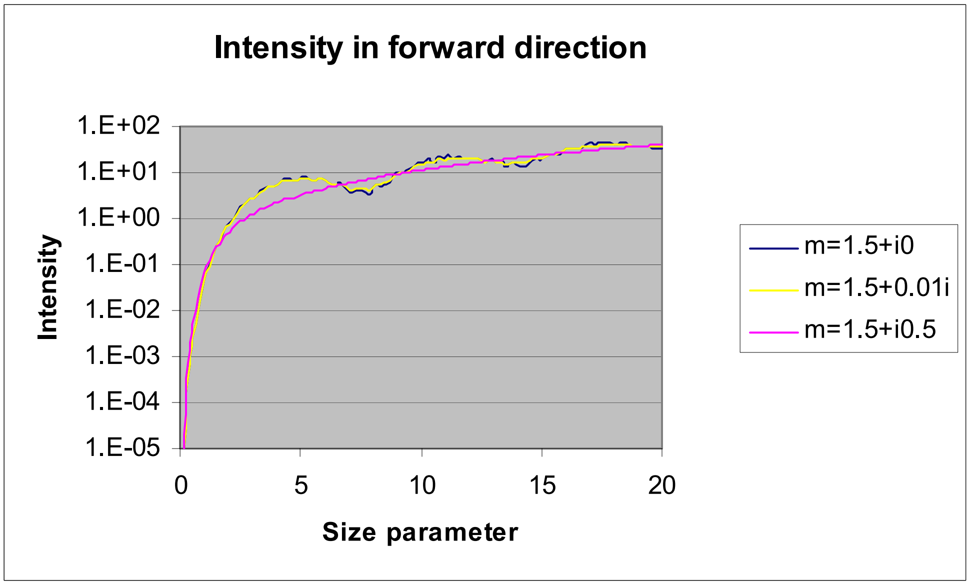


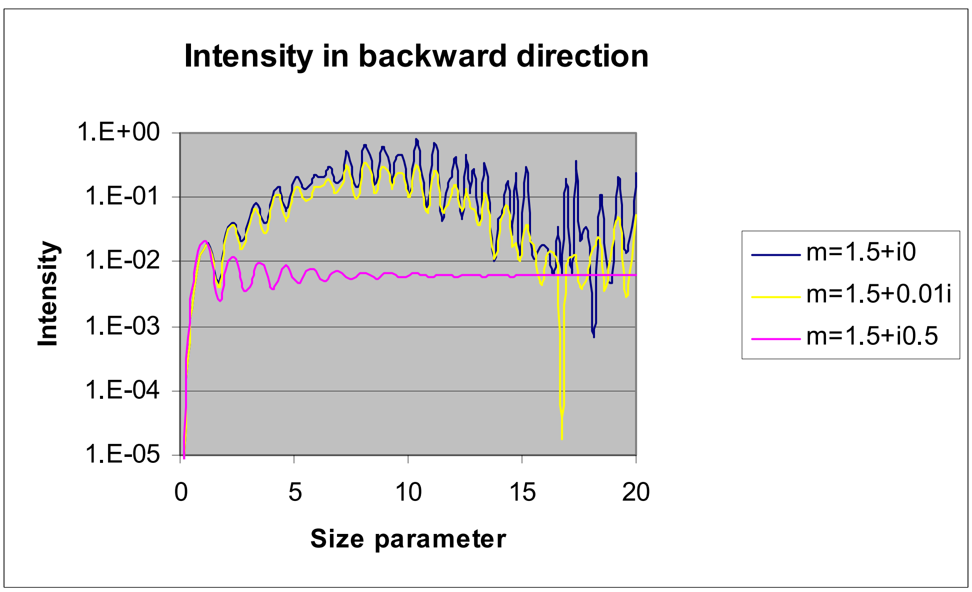
Small particle has zero liner polarization at 0 and 180-degrees scattering angles, while it is 1 at 105 degrees (full polarization).

Large particle produce variable polarization, while polarization at scattering angles larger than 90-degrees (backscattering polarization) is stronger than in forward scattering angles.

TASK 4

The intensity components in the forward (scattering angle =0^0) and backward (scattering angle =180^0) directions have special significance: the former being related to the transmission or attenuation efficiency and the latter to the backscatter of lidar beams in the atmosphere. Investigate the sensitivities of forward and backward scattered intensities to aerosol size and the imaginary part of the refractive index (assuming the real part is 1.5). Why may the measurements of backscattered intensity be more useful in aerosol studies than the measurements of forward scattered intensities?





The forward-scattered intensity has strong dependence on size distribution and will be strongly affected by scattering on large particles. The back-scattered intensity is more uniformly distributed as function of size parameter. For week absorption, the back-scattered intensity varies with size parameter (which varies with either radius of the particle or with wavelength of the observed back-scattered radiation), as well as with refractive index. Thus, it is easier to distinct between absorption parameters in backward scattering. For large absorption backscattered intensity is zero. So, we can distinct between absorbing and non-absorbing aerosols and find size-distribution of particles.